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Using the notion of 'wonder' to develop positive conceptions of science with future primary teachers

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ABSTRACT: A common challenge for many primary pre-service teacher educators is to rekindle interest in science content with future teachers who often express a lifetime of negative associations with school science. This pilot study investigated if the notion of wonder could be utilized with preservice teachers as a vehicle to develop more positive conceptions of science as an answer to our current 'crisis of interest' as described by Tytler (2007). Findings suggested the use of a wonder framework generated an increased interest and more positive views regarding science content. Key student cases demonstrated a shift in desire to learn science content that they had claimed to detest before engaging in the experiences related to the study. In all, the results of utilizing a wonder framework with adult students offered promising results. This study further argues that we may need to conceptualize school science as not just a way to understand the world but also to clearly demonstrate that it is a field of inquiry that is sustained by mystery, beauty and wonder.

KEY WORDS: wonder, inquiry, teacher education, case study, aesthetics

INTRODUCTION

There exists a crisis of interest in Science Education where, school science misses the mark for the nature and processes of science itself in favor of some sterilized, sanitized, and predictable form of science that often permeates science teaching and it "shows no sign of diminishing" (Tytler, 2007, p. 7). This is an exceedingly important notion when we extrapolate how this crisis may impact engagement with school science and teaching, "considerable evidence of student disenchantment with school science in the middle years, and a growing concern with a current and looming shortage of qualified teachers of science" (Tytler, 2007, p. 1). It is this crisis of interest that represents the focus of this research effort. In an extensive meta-analysis of student attitudes toward science and science instruction, Schibeci (2009) argued that this crisis was more a tendency for students to avoid science instruction at the "first available opportunity" and that our current pedagogical and policy approaches do not address the

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"affective aspects of students science experiences" (p. 108). These built on Tytler's (2007) prior findings related to the nature of classroom pedagogy and the implications that it has for school science approaches that were dominated by transmissive pedagogy and content that was not relevant to the lives of students, and educators efforts to seemingly make school science "unnecessarily difficult" (p. 9). We must remember that the students graduating from this school milieu are the very ones enrolling in our teacher education programs and we must face the reality that most of our future primary teachers do not have much interest in science after they finish their K-12 experience. Furthermore, prospective teachers often enter teacher education programs with negative views of their ability in science; however, they also articulate their desire to teach children in more effective ways then they themselves were taught science (Gilbert, 2009). This represents an important avenue for teacher preparation programs to investigate students desire to do something different than their own prior experience. To this end, Schibeci (2009) highlighted the need to consider science beyond simply in terms of content that can be measured toward a mindful space of imagination, possibility, and a desire to understand.

Consequently, this study endeavoured to better understand how to operationalize notions of wonder to impact scientific thinking and conceptions of science particularly with pre-service primary teachers to investigate if those could impact adult learners interest in science. The following questions highlight the overarching goals of this study: 1) Can the utilization of a wonder framework positively impact adult learners conceptions of science? 2) In what ways might a wonder framework impact student interest in science? Insight into these questions will directly address an increasingly important notion regarding how students perceive science and how we might facilitate student engagement with science content. These efforts are an attempt to effectively operationalize a notion of wonder with pre-service teachers.

THEORETICAL FOUNDATIONS FOR USING WONDER AS A FRAMEWORK FOR SCIENCE TEACHING

The Role of Wonder

> The lack of status of science teaching and learning in a crowded curriculum and the decline in students' attitudes towards further learning in science education are two major areas of challenge to New Zealand primary science educators (Milne, 2010, p.103).

I would argue the Milne's words could be attributed to most classroom contexts within the modern western world. The preponderance of weight given to standardized testing and ultra-focused curriculum efforts emphasizing Math and Literacy have come at the expense of other traditional

subject areas (Au, 2009). These curricular efforts have worked to streamline science into a predictable formulaic approach to science teaching (Milne, 2010). Many students, in these contexts, have had their scientific desire stripped from them throughout years of schooling that suppressed open-ended investigations and/or the pursuit of questions without clear answers. The future teachers who enter our programs represent a product of the system that honours control and predictability above the sometimes messy and seemingly unproductive pursuit of answers that vex them (Gilbert, 2009). In their experience, following rules and getting the one 'correct' answer is the goal of school (Leafgren, 2009). This rigid and streamlined vision of science may very well be attributed to teachers' uncertain ability for envisioning a different version of science then the one they experienced.

> Another aspect is the force of long habit of teachers who have developed effective ways of delivering canonical content, who may lack the knowledge, skills and perspectives required for the effective teaching of a different version of school science (Tytler, 2007, p. 18).

In Tytler's view, teacher candidates develop a high degree of pedagogical skill yet lack content background understanding and content related confidence, which directly impacted their desire to teach science in the primary context. In addition, primary teachers often approach science teaching with negative experiences and a distinct lack of confidence when it comes to teaching and learning science (Brand & Wilkins, 2007; Gilbert, 2009). This can impact future teachers' desire to engage with science as both a student and teacher. "Science education should therefore pay explicit attention to improving students' interest in and attitudes toward science, and this should take place beginning at the primary school level" (Van Aalderen-Smeets, Walma Van Der Molen, & Asma, 2011, p. 159). The authors go on to state that this is nearly an impossible goal if primary teachers are unable to conceive science from a positive viewpoint, "to achieve sustainable improvements in primary science education, it is crucial for primary teachers to develop their own positive attitudes toward science" p. 159. Thus, creating the positive experiences and attitudes for future teachers is essential to alleviate the crisis of interest and facilitate engagement with science content.

Luckily, science teachers have the ability to draw on students' desire to understand the world around them (Milne, 2010). Many researchers have delineated this special connection between children and their innate ability to wonder about the natural phenomena they encounter (Gallas, 1995; Hadzigeorgiou, 2001; Hadzigeorgiou, 2005; Howes, 2002; Hurd, 2002). Many times, disenchanted (often older) students may not recognize their wonderings as science, but it offers a place to begin. Zembylas (2004) provided further insights regarding the emotional roles at play

when challenging children to pursue the ideas that trigger their interest and wonder in science. This need to wonder has been suppressed by a system of schooling that desires to maintain order at all costs even if those structures limit student joy and enthusiasm of content related material (Leafgren, 2009). In addition, Leafgren (2009) argued that excellent teaching, that is inspiring to children, often falls outside the realm of quiet, orderly and predictable practice that has become synonymous with 'good teaching.' These notions of schooling as *control* exist in opposition to excellent science practice as evidenced by the advice from Richard Feynman (2005) for successful scientific endeavors, “Study hard what interests you the most in the most undisciplined, irreverent and original manner possible” (p. 206). We see similar insights from another professional physicist expanding on how to bring science to a broader educational audience, "the beginning of science is wonder, and in my view, the fostering of that wonder is the paramount task of science education at all levels of study" (Silverman, 1989, p. 44). It seems that those who have reached the highest echelons of scientific endeavor have done so by maintaining a healthy sense of wonder.

In terms of school science and primary children, multiple studies have found that when students engaged in cognitive struggle that it often drove them to seek out answers on their own and that it provided a powerful conduit for students to make connections to science content (Hadzigeorgiou, 2012; Hadzigeorgiou & Garganourakis, 2008; Varelas, Pappas & Rife, 2006). This point is echoed by Milne (2010):

> It can be argued that there is a strong similarity between the notions of awe and wonder and the elements of fascination and anticipation that children, engaged in aesthetic learning experiences, may experience. The awe and wonder factor … can become the focus or motivator for further thinking and enquiry (p. 106).

I do not contend that we should merely have children ask wistful questions, rather wonder frameworks can be utilized not just to inspire, but engage in meaningful scientific work. However, there are particular issues that must be addressed if we wish to seriously consider using wonder as a method to engage both science learners and teachers of science.

Critiques of a Wonder Framework

In order to reach the goals of both interesting our students in science and maintaining that interest over the long-term we must consider the implicit rules that govern how we view science learning and science itself. In his book that investigated a local science museum/tourist attraction named '*Robot World,*' Weinstein (1998) provided a powerful critique for the dangers of utilizing notions of wonder that are separated from the clear explanations for the science behind those wonderments. He states:

> The connection between science and wonder is part of an entrenched system of representation and is in no way unique to Robot World. It is generally accepted that wonder is the natural response to physical phenomena and the scientific discourses that speak for nature (p. 174).

Weinstein clearly articulated that many science contexts do try to exploit the idea of the unknowable where, "mystification acted to increase the effect of wonder" (p. 172).

Interestingly, Silverman (1989) warned that utilizing mysticism that can limit students in terms of wonder by undermining the ability to understand scientific phenomena and in turn dulling students' desire to learn. This is an essential argument to keep in the forefront as we conceptualize the utilization of wonder in any science context particularly those associated with school-based contexts. Weinstein also explicated this problematic notion of mystification as it was historically tied to a time when science and religion were closely related activities that did not allow for skepticism and interrogation of natural phenomena. To this end, Weinstein deftly placed this notion of wonder and how it is often operationalized into school-based contexts where, "children are seen as potentially not within the terms of scientific rationality and are therefore wild" (p. 178). Keeping these important critiques in the forefront of my mind, I am careful along two fronts. The first and foremost being, that wonder must be explicated as a tool for understanding as opposed to mystification or magic. Secondly, that wonder should not solely be the exclusive domain of the child as it seems to be framed in much of the current literature. Thus, wonder itself cannot be the goal of scientific endeavor; rather it must be utilized as the starting point for investigation.

Operationalizing the Concept Wonder: Moving Beyond 'It's just for children'

Most primary teaching professionals intuitively understand students' intense desire to understand (Gilbert, 2011). The average parent of a four-year-old child has almost undoubtedly experienced the incessant use of the word 'why' as their daughter or son begins to realize the potential of questioning in an effort to learn more about their surroundings. First off, we must consider that wonder is not just for children. To better express my thoughts here I present Ian Milne's (2010) articulation of "children's science" (p. 110) is a powerful notion that I am drawn to because of its reliance on experience and the construction of answers based on observation and evidence that mimics some essential notions of science itself as opposed to the mind-numbing memorization and vocabulary exercises that dominate typical primary science settings. Milne (2010) argued:

> It is about children's science; children personalising their science activity, leading to their development of creative explanations of natural phenome-

> na. It requires the children to be involved in exploration, inquiry, explanation and making connections and is often, can be, should be, based around or ignited by aesthetic experiences that promote affective and often emotional responses associated with the dispositions like fascination, anticipation and engagement and awe, wonder & interest that spark curiosity and can lead to the use of scientific inquiry to develop explanations of natural phenomena (p. 110).

I'm certain that most science educators who advocate for meaningful approaches would agree with the prior argument. Milne's departure from the typical inquiry approach lies mainly in the stated overall goals of the approach, which try to connect children with a sense of "awe, wonder & interest" (p. 110). These ideas represent an important contribution concerning the use of wonder and how we might operationalize teaching science with both primary children and adults alike. I feel that Milne's approach portrays a more realistic representation for the processes of science as compared to typical school science settings. However, I argue that these approaches would also provide benefits for adult students particularly those that carry negative associations with science. This description better represents an appropriate starting point for those wishing to engage in more realistic approaches to science regardless of age. For many scientists, collecting new sets of data or envisioning new problems can often lead to notions of excitement and wonder that we would often reserve solely for children. Science itself is rife with child-like enthusiasm as well as a strong connection to inspirational aesthetic qualities, no matter the age of the scientist.

In addition to Milne (2010), several other researchers have also articulated the essential role of the aesthetic in science contexts (Girod & Wong, 2002; Hadzigeorgiou, 2005; Wickman, 2006). These authors all advocated for connecting children with the beauty of the world around them as a way to help students become more engaged with the science content. The aesthetic quality of scientific investigation provides the necessary connection between the science student and the scientific ideas that are being investigated. "For this reason, the aesthetic element should also be sought in that personal experience of doing science, and hence linked to such notions as mystery, awe, wonder, imagination, inspiration" (Hadzigeorgiou, 2005, p. 41). These notions speak to rather an intense *need* to know and understand (Gilbert, 2011; Leafgren, 2009). It is this *need* to know that we must reignite in all of us.

These emotional cues can serve as important common ground for both students and teachers to explore as an effort to connect science content to our everyday experiences (Stolberg, 2008). This emotional engagement with science must be built into our classroom approaches and drive our pedagogy (Hadzigeorgiou, 2012; Zemblyas, 2007). Furthermore, connecting the emotive with science content can feed students' innate 'need' to

understand the world around them (Gilbert, 2011). The importance here is that the "need for cognition, therefore, should be associated with interest in science, because the latter begins with wonder, questioning, and curiosity about how the world operates" (Feist, 2012, pp. 772-773). This certainly speaks to the problems we face considering the waning interest in science across educational contexts. Therefore, it is imperative that we begin to generate interest in science and wonder frameworks offer some promise in this regard. Stolberg (2008) concludes that:

> … it is clear that both teachers and pupils need to be made more aware of the feelings wonder can engender. Pedagogical strategies need to be developed so that teachers can facilitate pupils to reflect on the possible meanings of the wonder, so helping them to develop a mature scientific voice (p. 1963).

This link between science study and the aesthetic provided powerful connections to content as well as significance to the identity of the learner. Hadzigeorgiou (2012) asserts that when utilizing 'wonder' as a pedagogical framework we must consider: the tentative nature of knowledge, the willingness to consider "unexpected connections between phenomena and ideas" (p.989) and an appreciation for the beauty of the natural world.

Utilizing these frameworks, I endeavored to engage adult science learners in meaningful science content as a method to rekindle the aesthetic spirit of wondering about the world. The following is my attempt to answer the *crisis of interest* that currently faces science education writ large as well as answer Stolberg's charge to develop 'pedagogical strategies' that help students utilize our special connections to wonder.

METHODS

Case Study Approach

The structure of this qualitative pilot study is best categorized as an instrumental case study, as described by Stake (1995, 2000). Instrumental case study differs from the traditional notion of case study research because the questions of the researcher are paramount as opposed to the case itself. This method is best utilized in a situation where, ‘‘we have a research question, a puzzlement, a need for general understanding, and feel that we may get insight into the question by studying a particular case’’ (Stake, 1995, p. 3). Thus, the research design was, ‘‘defined by an analytic focus on an individual event, activity, episode, or other specific phenomena, not necessarily by the methods used for investigation’’ (Schram, 2006, p. 106). The participants were 'purposefully sampled' to better understand particular student conceptions of science. The main value of utilizing this

approach was to study the complex situations that impacted the participants thinking toward science and to cast a light on what we can learn from these cases (Flyvbjerg, 2004; Stake, 1995). Lastly, I am drawn to a case study approach considering my ethnographic sensibilities in carrying out work with future teachers and the multi-layered issues at play within the lives of individuals, which are never easily quantified. Case study research allows for the methodological freedom (Stake, 1995) to utilize ethnographic data collection and analysis that were most appropriate for the questions that were investigated within this project.

Data Collection

Context and Participants. There were 24 students enrolled in the course titled: "*Science for Elementary Educators."* The five-week intensive summer experience was designed as a general broad-based science content course attending to the following key strands of science: Earth Science, Biology and the Physical Sciences. Not all students were required to enter the summer experience, only those students that did not meet the programs standard of C or better in at least six hours of semester credits (or nine hours of quarter credits) in the sciences needed to enroll. The goal of this post-graduate course was to provide a science primer for those wishing to enter the primary teaching certification program at our college in the following fall semester. The college itself was a small, suburban, liberal arts institution in the Pacific Northwest of the United States. The students represented a range of both ability and interest, but most fit the well-publicized notion of the primary student that fears and/or has little interest in science itself. All the students were white with the gender distribution consisting 22 females and 2 male students. Most of the students were in their early 20's, with a just 4 students between the ages of 30 and 50. This profile generally fits the typical profile of the primary teacher in the Untied States (Gilbert & Williams, 2008).

In addition to looking at issues from across the range of students in the course context, the study also closely investigated three individual cases. These cases were purposefully selected because they represented wide-ranging interest in science, which should provide broad perspectives concerning the utilization of a wonder framework. The following descriptions provide brief context for the three individual cases of Amy, Laurie and Sierra (pseudonyms). *Amy* was in her mid-20's and was a successful student throughout her school life. She worked for a few years as both a youth counselor and community organizer after obtaining her undergraduate degree. Her father was a scientist and often provided her with science experiences during her home life. *Laurie* was in her early-twenties returning to school seeking a job opportunity that offered her a greater sense of fulfillment. She worked as a manager of a local food coop. A job she started after right after graduation from university the previous year. *Sier-*

ra was a stay at home Mom in her mid 30's and was coming back to school to pursue a career that "would fit" with her children's schedule as they progressed through school.

Data Artifacts. In order to envision the operationalization of a wonder framework I have gathered a series of data sets including: items related to student wonderment projects (wonder list, concept map assessments, and associated research projects associated with their wonder concept) and an audiotaped discussion with research scientists. There were also more common data collection techniques, which included a brief initial survey, reflection on prior science experiences, written final examination and exit interviews with selected students. The wonderment project began with a list of 25 wonderments students had concerning scientific phenomena. There were no rules here just that they list anything they found peculiar or did not fully understand. The goal with such a large number of items was to force the students to think deeply about a range of issues as opposed to simply jotting down a few quick ideas. The concept map was a formative assessment carried out near the end of the course experience. The students constructed them from memory without access to their research notes. Lastly, students carried out research presentations based on their findings into their wonder research and constructed final written reports on the wonderment topic itself.

Another major piece of data collected were students' reflections on their prior science experiences and visions for science itself. This reflection was modified from Gilbert's (2009) approach with the utilization of science philosophy statements. Students were asked to articulate their own visions for what constituted science as well as highlighting their prior science experiences both inside and outside of school. This provided me with insights into the dispositions that the students carried with them into the summer experience.

In addition to these data, I interviewed each of the case study students at the close of the experience. The interviews were typically thirty-minute semi-structured interviews. These individual interviews served two specific goals: (1) a means for exploring and gathering experiential narrative to develop meanings of experience, and (2) a vehicle to develop a conversational relation about the meaning of that experience (Bogdan & Biklen 1998; Van Manen 1990). Semi-structured interviewing methods were used to create a more conversational interview style and facilitate researcher and subject to achieve a more equal relationship (Hitchcock & Hughes, 1989). Fontana and Frey (2000) argued that less structured interview techniques establish more human interactions between the respondent and the researcher, where the researcher is fueled by a, "desire to understand rather than explain" (p. 664). In totality, these data sets provided an array of insights concerning the utilization of a wonder framework and

provided a clear vision for the impacts this approach can have with adult learners.

Data Analysis. This approach to data gathering was predicated on the existence of multiple truths and that understanding is often incomplete and multi-layered (Ladson-Billings, 1994). Thus, multiple sets and differing types of data were utilized in an effort to sustain credibility (Lincoln & Guba, 1985). For further credibility, interpretations were also triangulated across all data sources. This triangulation, coupled with member-checking efforts, worked to consistently align my interpretations to best match the feelings and thoughts of all participants involved (Patton, 1990).

Discussion and interview sessions were recorded and transcribed immediately following their collection by the researcher. These transcripts as well as reflections (of both participants and researcher) were printed for further analysis. These data sets were then subjected to multiple complete readings in an effort to generate a preliminary list of possible coding categories (Miles & Huberman, 1994). This provided a mechanism to reduce large amounts of data into more manageable categories across similar themes. These initial categories where then subjected to constant comparison and analysis across all data sets in an effort to develop a working set of emergent themes as described by Strauss and Corbin (1998). This process of generating possible categories, confirming or contradicting those categories with multiple sources of data, followed by subsequent modification continued in an iterative process until the final analysis was reached (Bogdan & Biklen, 1998). All participants were given the opportunity to member check findings; however, only one student chose to take part in reading the interpretations of the study. The participant agreed with the interpretations and meanings placed upon the data presented.

FINDINGS AND DISCUSSION

How the Students Viewed Science

One of the first efforts with the group was to make sense for how these adult learners had engaged with science and how they conceptualized themselves as both consumers and users of science knowledge. I provided the students with a survey that asked a few key questions about their views concerning their personal connections to science (see Table 1). Using a brief Likert Scale questionnaire, I asked students to rate their interest in science. Sixteen of twenty-four respondents marked themselves at a level of 1 or 2. Meaning they felt very little interest in science whatsoever. In addition, two of these respondents demonstrated their antagonistic feelings toward science learning writing, "hate it" and the other student writing, "so boring" directly on the survey itself. Of the remaining eight learn-

ers, most identified as neutral or somewhat interested with one student claiming to be very interested.

Table 1. Student responses on overall views toward science

1 - no interest	2 -little interest	3- neutral	4 - somewhat interested	5 - very interested
6	10	4	3	1

I would argue that these results mimic my past experiences with future primary teachers as well and I was certainly not surprised by the depictions of the students in this summer experience. The survey provided some instant insight into overall complexion of the classroom community.

This limited survey question provided little in the ways that students have come to this understanding. For more insights, student science experience reflections were utilized to shed light on these mostly negative views for science. The goals associated with student construction of these reflective statements provided teacher candidates with important opportunities to locate and internalize their own professional beliefs as well as make sense of the ways in which they have engaged with science content in the past (Gilbert, 2009). Explicating student views on science provided a more detailed vision for the dispositional background of students involved in the study. One of the most interesting aspects of this data set was the remarkable similarity in how they described their previous science experiences particularly in regard to school science experiences.

> I absolutely loathe science. All of my previous science experiences in school were based on reading, discussing, and test. I never felt that I was able to get a solid understanding of it [sic] purpose, which sometimes makes me question its motives. - Sierra

> I remember not enjoying science very much. I don't have many memories of fun and exciting science experiences in school and I always thought that it was because I considered myself to be "bad" at this specific subject. Throughout all my school years, science seemed to be the subject that I enjoyed the least. - Laurie

> In most of my elementary school years I viewed science as just another boring subject, as I viewed math. Most of the time, science was done with worksheets and textbooks, but I have such good memories of it with my father. - Amy

It is not hard to conceptualize where these students' mostly negative views of science derived, nearly all of them articulated it was the nature of school science that eroded their interest. The question became how might we learn to move them forward and get deeper insights beyond "my teachers didn't teach me well." There were several key ideas that emerged

from analyzing these student statements and that 1) there existed a clear disconnection between how teachers and students viewed science and science learning; 2) the rigidity of school science curriculum did not allow for deviation into areas of interest; 3) the ultimate goal was to find one pre-determined answer. By contrast, there were a few students, who had more positive views of science and they described engaging in science outside of school contexts. In general, however, those students with more positive views of science represented a minority within the study.

Wonderment projects as a window into student conceptions of science

I sought to counteract students' problematic visions of science by disrupting commonly held notions of science and science practice in primary contexts. My main effort here was to create a more realistic view for both the processes of science and people who carry out scientific endeavors. In an effort to operationalize wonder in the classroom context the course was constructed around the enactment of wonderment projects. The projects began by having students to list 25 things they wondered about with no limitations on those thoughts. I decided not to narrowly define notions of wonder for my students and let them interpret that notion for themselves. Students were given complete latitude in how they wished to utilize the notion of what it meant to wonder. They were intentionally not provided with examples or what I considered to be a proper wonderment. The goal was for them to be unfettered by any possible constraints. Stolberg (2008) demonstrated that there are three distinct categories pertaining to wonder:

1. Physical wonder, which is prompted when interactions with objects, phenomena or processes found in Nature are the stimuli.
2. Personal wonder, which is prompted when interactions with human beings or their work are the stimuli.
3. Metaphysical wonder, which is prompted by any type of interaction, but the wonder evoked goes beyond a reflection on the original stimulus (p. 1960).

What I found surprising from this assignment was not only that the students wonderments clearly followed Stolberg's three categories related to *wonder*, but also how the listing of ideas clearly demonstrated differing levels of student understanding and confidence within science. In totality, it was easy to discern which students had more experience within the sciences as well as increased confidence in the types of questions and wonderments they raised.

Let's first consider Sierra's list of wonderments (Appendix A). The list demonstrated a somewhat unsophisticated view of science through many of her questions, i.e., #10 Why do infections in the body smell like dirty feet? However, we are able to see more deeply into Sierra's scientific conceptions as she continued further down in her list, when she asks:

14) If scientists in the past have been known to misappropriate data to prove that blacks and Jews were inferior humans [sic], then how do we believe beyond a reasonable doubt that other truths they claim are fact not fiction?
15) Is it possible to scientifically prove that the Garden of Eden and the evolution of man from apes [sic] both happened upon this Earth?

By taking away limits on student thoughts and pushing them to think of multiple examples concerning the ideas about which they wonder, provided interesting insight into ways they conceptualized science. These notions most likely would not have come out during a typical interview or reflection session. In Sierra's case, she made mention of questioning sciences' motives. In her few questions we see a multitude of issues rising to the surface. For instance, equating the work of Nazi propagandists and those engaged in eugenics, as an effort to question all aspects of science is most certainly problematic. In the next question, she offered more insights into her desire to question science on religious grounds as well as her misunderstanding for human evolution as man descended from apes as opposed to a common ancestor. Thus, the wonderment list also in some ways served as an initial assessment tool. It also clearly demonstrated which students were more comfortable with science content as they wrestled with more sophisticated wonderments. To this end, Amy's wonderment list (See Appendix C) provided insights for how she was clearly trying to make sense of large-scale questions related to cosmology:

7) Is space something or nothing?
8) If atoms are made up mostly of space, and the universe is made up mostly of space, then I wonder if space is made up of something that we have very little capability to observe. What is the influence of all that space? What is the influence of the expansion of space?
9) Did the elements spontaneously come into existence?

We see from Amy's line of questioning that she has had some Physics background that she remembers, but is also pushing against the unknowable. These are the types of questions that simmer with students as they work to make sense of the world in which they live. It is exactly these types of questions that will interest them in the pursuit of their research project as well as the classroom activities dealing with associated content.

Impacts on Student Interest

As a follow up to making the wonderment list, students were asked to choose one of their topics and develop a research question from it. This aspect of the study provided prospects for addressing the *crisis of interest* we face in science education. Mainly, the students had total control in what and how they would go about researching for their final content pro-

ject and it showed as most of the students worked diligently in developing and researching their content wonderment. In the end, students presented their ideas and findings on their research project along with a formal position paper on their wonderment. This project was carried out while students also worked on more traditional science content through the use of inquiry-based pedagogy dealing with major aspects of the primary curriculum during the so-called 'lecture' portion of the class. As students worked on their individual projects we began to see them making connections between curricular areas and demonstrating the notion of transfer. In one instance, Laurie whose first wonderment (See Appendix B) was related to swim bladders in fish expanded as she began to investigate that notion she was reminded of something she found even more interesting was how fish, particularly Salmon, understood their migratory patterns. This eventually expanded into other migratory animals, etc. As her work progressed, Laurie discovered that research suggested that Earth's magnetic fields were the major mechanism guiding this animal movement. The pursuit of these answers was fueled by her own interest, which ultimately led her to change her wonderment project topic to the formation and nature of Earth's magnetic fields.

Three weeks into the summer experience, students constructed concept maps that laid out the major issues associated with the wonder projects. These were done without access to notes and students were asked to represent their ideas, as they best understood them at that point (Appendices D, E, and F). Concept maps have proven to be important tools for teachers in both terms of assessment and as a metacognitive tool that reflects students' scientific thinking as they work to learn new science related content (Rollnick, Mundalamo, & Booth, 2012). Consequently, I chose them as a non-threatening assessment tool as well as a mechanism for students to continue to hone their ideas in relation to their individual research projects. The students demonstrated a range of understanding and depth of thought with the concept mapping exercise. The maps of Laurie, Sierra and Amy depicted the overall classroom range quite well. In general, most students demonstrated a high degree of understanding as it came to both their concept maps and their narrative description for the science underpinning their wonderment. In particular, Laurie's interest pertaining to animal migration led to her increased interest in Earth's magnetic fields, which she described in the following way in her narrative description that accompanied her concept map (Appendix D):

> The outer core of the Earth is composed of liquid iron and nickel and its movement is characterized by both convection currents and the rotation of Earth. Movement of the conductive liquid iron creates 'rolls' of currents, which sustains the magnetic fields. These fields actually protect the planet by radiating out and deflecting solar wind.

The connection between plate tectonics, earth's core and the navigation of fish and bird species was an interesting one that Laurie made between an inquiry lesson on plate tectonics theory (during the course) and her own beginning research. This grew from her sense of wonderment and her desire to better understand a question that vexed her. Laurie described her thoughts on the project during her final interview where she stated the main benefit she felt she would take away from the project was that she "experienced the passion of being a scientist." Laurie's words are important along two fronts: 1) being that she saw her research and thinking associated with the project as doing real science and 2) her depiction of this work as a 'passion' is essentially important because the main goal of this study was to investigate the degree to which wonder could stimulate adult learners interest in the sciences. In Laurie's case we can make some determinations for a wonder framework's ability to stimulate the interest of students in pursuit of questions that interested her and something she was passionate about. I certainly, as an educator, would not have connected swim bladders with magnetic fields, but this was a direction that Laurie found interesting and fulfilling and along the way she certainly made sense of a broad array of science and scientific understanding. That being said, it was also certainly a goal of the course to increase student understanding for content areas associated with primary science teaching. Not surprisingly, as interest increased so did students willingness to engage with the associated content. What is important to remember is that Laurie never saw herself as successful in science and in fact portrayed herself as "bad" in science (during both her initial reflection and final interview) yet she clearly demonstrated potential within this project approach.

Several students depicted the process of constructing their wonderment list as a means of identifying areas of science they needed to brush up on. However, there were a few key questions that seemed to create a spark; however, just wondering about those questions was not enough. It was the pursuit of those answers that made the wondering worthwhile. Amy stated in her final interview that, "I think that I still valued investigating the answers over the act of wondering." This was the goal of the project to utilize the process of wondering to trigger the pursuit of answers.

In another case of interest being triggered through wondering has to do with the course approach to Earth History. Although not systematically controlled or tested as a part of this research effort, there were formative and summative assessments that helped guide my efforts throughout the summer session. In this case, 23 of 24 students clearly indicated a lack of understanding regarding the age of the Earth and in reality knowing the age of the Earth will have little bearing on students' everyday lives. The process of engaging students was carried out through providing content and experiences representing how scientists' own wonderings drove their

efforts to ascertain the age of the Earth. We studied Claire Patterson's life work with radioactive decay as a method to date the Earth so that they had a better idea where these age determinations came from. In the next class section, students constructed a 4.6 m timeline that needed to include demarcations for the major eras of Earth time and at least ten events across the enormity of that time span (first rocks, rise of mammals, extinction events, etc.). Students then undertook writing a reflection based on issues that they still wondered about in terms Earth history. This approach seemed to resonate even with self-proclaimed science hater, Sierra, who stated in her final reflection on the course:

> I got interested in things that surprised me like Earth History…it's not something I've *ever* been excited about, you know, but after doing the scale timeline I've become a lot more interested in everything we don't know about the Earth. And, how do we know what we know?

It seems that by taking an investigative, representational approach informed by wonder impacted Sierra's interest in the topic and she references what we still do not understand as something that has sustained her interest in these ideas. This speaks directly to Tytler's (2007) crisis of interest and provided more evidence that wonder frameworks can positively impact student interest. Sierra's increased desire to learn about these issues speaks loudly considering she once declared that, "I absolutely loathe science."

CONCLUSIONS

This study has provided insights into some exciting possibilities concerning the utilization of a wonder framework for inspiring students to engage with content in an effort to ultimately increase their scientific understanding. The data does suggest that interest was increased particularly concerning topics that students engaged in with their wonderment project questions. Throughout the process students delved deeper into content-related issues than I would have normally attempted with preservice primary teachers (such as Amy's work with cosmology and Laurie's detailed analysis of Earth's magnetic fields). However, one of the most exciting aspects of this initial effort was the beneficial impact that utilizing a 'wonder framework' had on those students who openly declared to have antagonistic views of science (exemplified by Sierra). Sierra's content understanding was still behind many of her classmates, but there existed a serious change in how she described her interest in science related topics, which should provide a powerful answer to those writing about the 'crisis of interest' that we currently face in science education and primary science education in particular. This could have important implications for both Sierra's future science efforts as both a student and future teacher.

Wonder proved to be an effective starting point for scientific investigation, which in turn, triggered interest in even the most ardent science haters. It is possible to help future primary teachers remember and rekindle their ability to pursue meaningful science in their lives. However, wonder is not often associated with the ways in which the public views science. Science has often been portrayed as difficult and beyond the reach of the average person (Kirby, 2003). For anyone who has watched even one episode of *The Big Bang Theory* we quickly find the stereotypical notions that encompass the public's vision for scientists in the western worldview. They are by nature: peculiar, obtuse, social outcasts who are also disdainful of unscientific thinking. However, introducing the students to actual research scientists who discussed ideas they did not know and/or how they openly embraced ambiguity provided students with a human face of science and the courage to better understand that starting a scientific investigation to find the answer to something you already know makes very little sense. Wonder provided a framework to take these more realistic understandings for the process of science and place science content directly into the minds of these future primary teachers. This moved the group beyond the simplistic notion of finding the 'one right answer' to every problem toward an understanding that answers are often contextual with multi-layered solutions and differing viewpoints. In many cases their wonderment projects led them to more questions, which served to feed to their enthusiasm and interest in related science content.

Wonder frameworks provided interesting possibilities particularly for science resistant students. All three cases provided some compelling evidence for facilitating students to envision new possibilities regarding science study. The utilization of wonder moved them beyond the notions of boredom and difficulty they expressed in their past experiences with science toward an activity that carried increased value for them. This study provided evidence for addressing the 'crisis of interest'; however, further research is needed to better understand if this higher level of interest equates to gains in content knowledge understanding. This study was not designed to measure students' science content growth. However, classroom-based assessments did hint at student content gains over the five-week session. This indicates promise for wonder perspectives in terms of interest and retention. Therefore, future research efforts should work to investigate links between pedagogical approaches steeped in wonder and science content gains.

Lastly, this study wished to problematize the notion that wonder and wonderments are the sole regime of the wistful child. As Carson (1956) warned that adults have been conditioned to disobey their sense of wonder as well as key questions concerning their everyday existence. Therefore, when working with pre-service teachers (adult students), I am envisioning an effort to rekindle wonder as an invitation to think in less disciplined

ways and allow for those thoughts to trigger a desire to focus their efforts toward understanding their everyday lives. The lesson learned for me as both a teacher and researcher is to listen closely to students and continue to find ways to connect student interest to ideas within the curriculum and realize that utilizing a wonder framework may not necessarily have total congruence with large-scale standardization efforts. To this end, I do not pretend that utilizing a wonder framework would fit easily into the current structure of schooling that is typified by increasing compartmentalization and reliance on standardized assessment in the western world (Au, 2009). Rather, assessment for these types of approaches would need to be school-based and contextual to best represent the deeply complex processes happening as students engage in the work of real science. Tytler (2007) reminds of this mismatch:

> Given that many of these practices involve tasks that are student-led, local and current in context, and involve broader skills such as analytic thinking and communication, it is difficult to imagine the development of examination-based assessment that will do justice to these. Rather, it seems more feasible to develop approaches to assessment that are embedded in serious, longer term activity, and which therefore will involve teacher judgment and moderation. This would constitute a challenge to current directions in state and national assessment practice, which currently threatens to close down variation and innovation by pursuing a narrow version of accountability through tight specification of content (p. 66).

This remains a serious challenge to enacting more dynamic approaches in science classrooms. If we are truly serious about curtailing the burgeoning 'crisis of interest,' we must push for more dynamic methods of pedagogy and assessment that better match the actual processes of doing science. To this end, a wonder framework provided powerful possibilities for rekindling the science interests of those adults who have had the passion of wonder slowly extracted from them, as they became institutionalized visions of schooling itself.

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APPENDICES

Appendix A: Sierra's wonderment list

1. Why does the grass that my dogs pee on look so green and luscious and grow faster than the other grass?
2. Why do I have two ureters exiting one of my kidneys and what difference does that make for my bodies processes?
3. Why does moss grow on one side of trees primarily?
4. Why does the heat in the summer make me tired?
5. Are there more grains of sand on the earth or stars in the sky?
6. What type of soil would be worthy of geologists studying it biyearly?
7. How do you convert salt water into fresh water?
8. Is genetically altered food better or worse for the human body?
9. Why is rust so hard to remove?
10. Why do infections in the body smell like dirty feet?
11. Are tanning beds really a good substitute for obtaining vitamin D that Washingtonians lack from sun exposure? Can you get cancer from tanning bed rays?
12. If epigenetics could influence the evolution of other species on this planet, or are other species capable of making epigenetic changes?
13. What does my carbon footprint look like?
14. If scientists in the past have been known to misappropriate data to prove that blacks and Jews were inferior humans, then how do we believe beyond a reasonable doubt that other truths they claim are fact not fiction?
15. Is it possible to scientifically prove that the Garden of Eden and the evolution of man from apes both happened upon this earth?
16. If the brain rewires itself to interpret sign language for deaf people does the brain create different neurological pathways to interpret sounds for the blind in the same way?
17. How far below the earths crust have humans traveled, or how far have we been able to dig?
18. Why does umami bother the body without a gallbladder?
19. What are gallstones made from?
20. If I needed an eye transplant would I see things differently through the eye than before?
21. What is it like to feel sound in your body, but not hear it?

Appendix B: Laurie's wonderment list

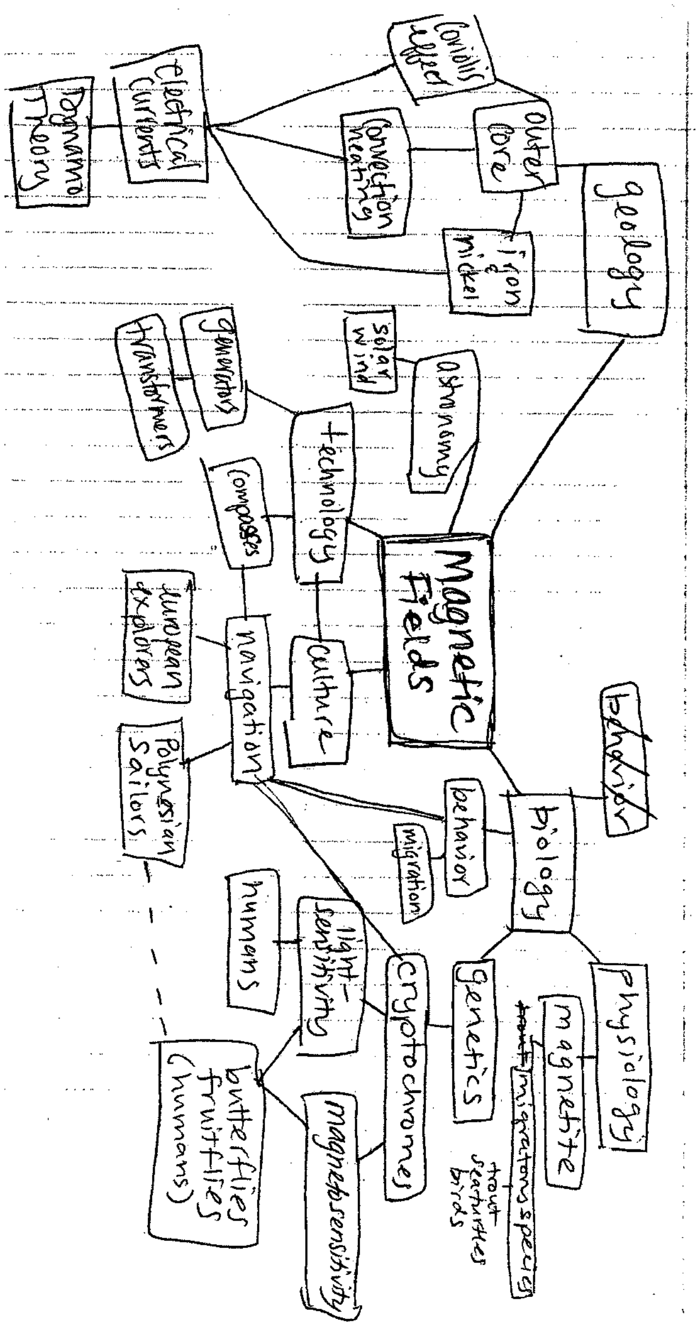
LIST OF WONDERS!

1. How do fish air bladders work?
2. How do you measure the density of huge, immovable objects?
3. How do barometers work?
4. Why is weather so hard to predict?
5. How does bleaching work?
→ 6. How does the sun (UV) sterilize water?
→ 7. How do spicy foods cool us down? Do they?
8. Why do some surfaces become super slippery when wet, as opposed to others?
9. How does styrofoam recycling work?
10. When you lose weight, where does it go?
11. How do ants know how large things are around them? – ex. how do they know they can pick up a huge chip?
12. How do insects experience time?
13. How do CFL bulbs work?
→ 14. What is the chemistry of baking?
15. Why do cars wear out? What goes first?
16. Why does beer float? Sugars + carbs?
17. Why does salt water freeze more slowly?
18. Why do some fruits not ripen once picked + others do?
19. How do people develop tolerances to some things (caffeine) + not others.
20. How do marine animals experience sound? 21. Does sound/light travel slower or more quickly underwater?
22. Where do all dead animals end up – birds, especially. I realize they are eaten + decompose, but where do they go?!

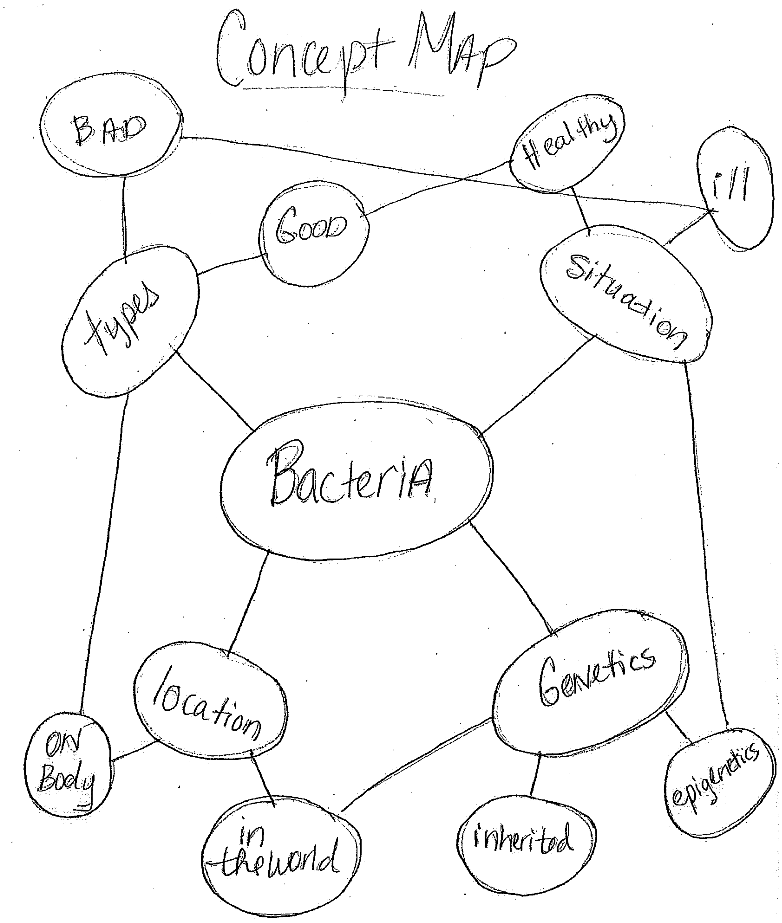
Appendix C: Amy's wonderment list

1. Why isn't the summer solstice ever the hottest day of the year in Olympia?
2. Why do scientists think that if we could try to find the edge of the universe that we would only arrive back at where we began?
3. Does the expansion of the space between objects in the universe slow as time progresses?
4. If the universe began from nothing, then could something begin from nothing in the vast areas of empty space within our universe?
5. Does the universe expand at a faster speed than the speed of light? Does the expansion of the universe effect the amount of light years it takes to see light from far away galaxies?
6. They say before the "big bang" there was not even space, how is that possible?
7. Is space something or nothing?
8. If atoms are made up mostly of space, and the universe is made up mostly of space, then I wonder if space is made up of something that we have very little capability to observe. What is the influence of all that space? What is the influence of the expansion of space?
9. Did the elements spontaneously come into existence?
10. If sister particles respond instantaneously when separated to movement instigated on one of them regardless of space, then is space irrelevant?
11. Is gravity on earth effected by the gravitational pull at the center of the milky way?
12. Is gravitational pull effected by the expansion of the universe?
13. What makes it possible for us to create a gravity free chamber on earth?
14. Does sound exist in outer space?
15. How does sound effect the particles around it in nature?
16. What is the relationship between consciousness and matter? How do we observe that relationship?
17. Does modern life affect human physiology to the degree that we have evolved (even marginally) from the first homo sapiens?
18. Are instincts genetic? Can learned behavior disrupt the power of instincts?
19. How do new neurons form in the brain?
20. Can mushrooms really save the planet?
21. Has a species ever brought about its' own extinction?
22. Why does the moon appear to change size and color?
23. Do animals telepathically communicate?
24. How does acupuncture work?
25. Do the recent hurricanes, tornadoes and tsunamis indicate an increase in these events according to history, and if so why?

Appendix D: Laurie's concept map



Appendix E: Sierra's concept map



Appendix F: Amy's concept map